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D. Zelenchuk, and V. Fusco

The paper reports on a split ring slot FSS reflector whose element design and distribution allows generation of far-field difference patterns. The reflector operates by converting linearly polarized plane wave fronts into two orthogonal polarizations each with a deep null in the centre of the radiation pattern. The far-field measurement presented is in a good agreement with the simulation and demonstrates a null depth of -20dB in the centre of the radiation pattern.

Introduction: Antennas with difference far-field radiation patterns are used for target location in radars or in astronomic observations where a darker object at the periphery of a bright object is to be observed. In this letter we propose a new type of 2D reflectarray whose elements are distributed such that it generates a null in the radiation pattern in two orthogonal planes for linearly polarized plane wave excitation.

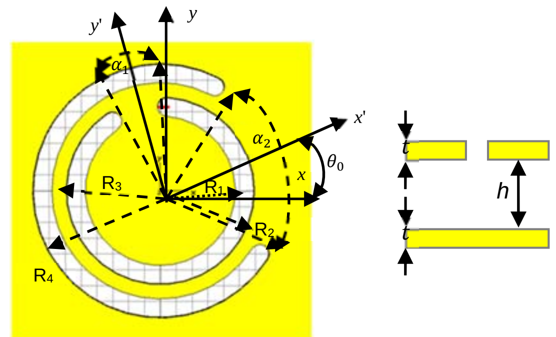
Design of the reflectarray surface: With reference to the unit cell shown in **Fig. 1**, let us assume that a linearly polarised wave of frequency ω propagating along negative z direction is incident on the reflective FSS:

$$E_{i,LP} = E_0 \boldsymbol{a}_x e^{jkz} \qquad (1)$$

E_0 is the amplitude of the electric field, $\boldsymbol{a}_x$ and $\boldsymbol{a}_y$ are the unit vectors of x and y axes correspondingly, k is the wavenumber, the time dependence $e^{j\omega t}$ is omitted here and in further considerations. If one designs the structure that $\Gamma_{x'} = -\Gamma_{y'}$, where $\Gamma_{x'}, \Gamma_{y'}$ are the reflection coefficients for the waves linearly polarized along the axes $\boldsymbol{x'}$ and $\boldsymbol{y'}$, respectively, the structure will exhibit the properties of a half-wavelength wave plate [1] and be reflected as,

$$\boldsymbol{E}_{r,LP} = E_0(\boldsymbol{a}_x \cos 2\theta_0 + \boldsymbol{a}_y \sin 2\theta_0)e^{-jkz} \qquad (2)$$

The angle θ_0 denotes rotation of the double split ring slots within the unit cell, **Fig. 1**.



a *b*

Fig. 1 *Double layer structure under test:*
a top view
b side view

Table 1: Parameters of the unit cell

R_1, mm	R_2, mm	R_3, mm	R_4, mm	α_1,°	α_2,°	h, mm	t, mm
4.7	5.9	6.8	8	21	95	7.5	1

For 180° phase difference between the reflection coefficients at the specified operating frequency of 10.4 GHz the dimensions of the periodic FSS optimized through CST simulation are given in the **Table 1**. The unit cell is square with a period of 19 mm.

Next, we design a finite 10x10 reflect array with unit cell dimensions as given above wherein its individual elements are rotated spiral fashion such that they have a relative rotation between them of $\theta_0 = \phi/2$, where ϕ is azimuth angle, **Fig. 2**. By substituting this rotation pattern into (2) one can find that upon excitation with plane wave polarised along x-axis (1) the reflected field distribution on the surface of the array contains two orthogonal components

$$\boldsymbol{E}_x = E_0 \cos\phi\,, \qquad \boldsymbol{E}_y = E_0 \sin\phi \qquad (3)$$

It follows from (3) that the field distribution for reflected x- and y-polarized components has odd symmetry in x-z and y-z planes correspondingly. Therefore the far-field will exhibit difference patterns. **Fig. 3** shows CST Microwave studio predicted reflected far-field patterns of E_θ component [2] in orthogonal x-z and y-z planes when the surface is excited by a normally incident linearly x-polarised signal.

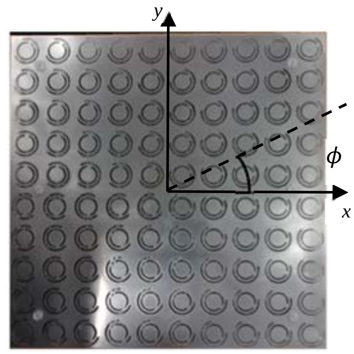
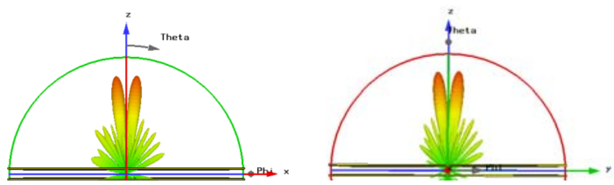


Fig. 2 Reflectarray with azimuthally rotated elements



a *b*

Fig. 3 Simulated reflected far-field pattern of the 10x10 reflectarray excited with plane wave polarized along the x-axis at 10.4GHz

a E_θ for $\phi = 0°$ and $-90° \le \theta \le 90°$, θ is polar angle of the spherical coordinate system.
b E_θ for $\phi = 90°$ and $-90° \le \theta \le 90°$

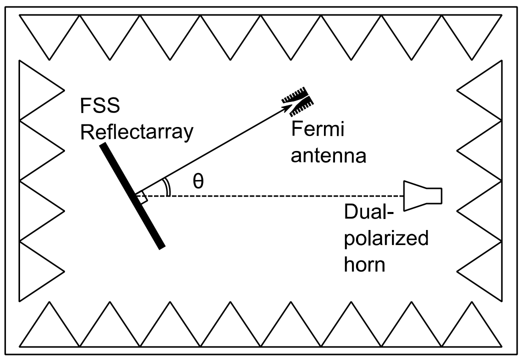


Fig. 4 Measurement setup in anechoic chamber.

Measurements: The reflectarray was manufactured, **Fig. 2**, and bi-static far-field measurements performed as shown in **Fig. 4**. The reflectarray was illuminated with a 20 dB dual-polarized standard horn placed at 6 m distance from the screen. The screens response was observed using a linearly polarized Fermi antenna [3] with 30º 3 dB beamwidth in both E- and H-planes positioned normal to the FSS reflectarray surface and 1.35 m from it, (90º rotation of the Fermi antenna allowed orthogonal polarisations to be tested while preserving the phase centre of test setup). Both the array and Fermi antenna were rotated simultaneously during the radiation pattern scans.

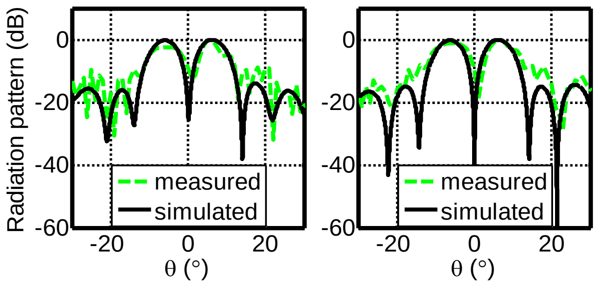


Fig. 4 Comparison of simulated and measured radiation patterns (normalised) when excited by a normal incidence x-polarized plane wave at 10.4 GHz.

a E_θ for $\phi = 0°$ and $-90° \leq \theta \leq 90°$
b E_θ for $\phi = 90°$ and $-90° \leq \theta \leq 90°$

The results of the measurements are in agreement (to the limits of our experimental setup) with the simulated ones as demonstrated in **Fig. 4**. As predicted, one can clearly observe the distinctive null in the centre of the radiation pattern for both co- and cross polarized responses. The measured null is more than 20 dB below the two main peaks it for the cross-polarized wave and below 12 dB for the co-polarized case. The difference is explained by the fact that in the measurement near to boresight the Fermi antenna partially scatters the incoming plane wave. Due to the composition of the Fermi antenna [3] its radar cross section for the co-polarized excitation is higher than for cross-polarized, hence the response degradation. The noise in the measured data is associated with the multiple reflections from the walls of the anechoic chamber, which could not have been mitigated within our measurement capabilities.

Conclusion: A new type of reflectarray surface has been demonstrated to be able to simultaneously generate linearly polarised far-field difference patterns in two orthogonal polarizations when excited at normal incidence by a linearly polarized plane wave. The technology presented here opens the way for a new generation of antennas for use in radio astronomy or radar use.

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